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THE DESIGN OF MASS SPECTROMETER ASSEMBLIES  
FOR SPACE SHUTTLE LAUNCHED SATELLITES

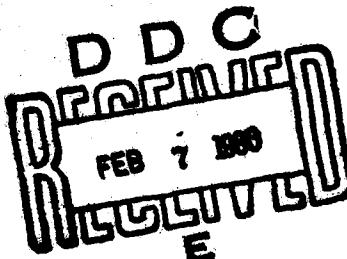
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George P. Murphy

TRI-CON ASSOCIATES, INC.  
765 Concord Avenue  
Cambridge, Massachusetts 02138

September 1979

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><i>This report discusses the development of instrumentation to be flown on satellites which will be launched from the space shuttle.<br/>The instrument is a quadrupole Mass Spectrometer designed to measure pre-selected masses in the 1 AMU to 50 AMU region. A discussion of the various circuits will be included in this report along with a complete set of Schematics and Drawings.</i> |                       |   |

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## 1. INTRODUCTION

The objective of this contract was to Design, Develop and Fabricate three mass spectrometer assemblies to be used for ion composition studies during the Space Shuttle Program.

This report discusses the operation of the electronic circuits, and the mechanical layout of what is referred to as the "LASSII" Mass Spectrometer Experiment.

There are two packages to each instrument, one referred to as the Electronics Package and the other referred to as the Sensor Package.

The Sensor Package does contain some of the electronics discussed in this report such as the electrometer amplifiers, RF Oscillator and High Voltage Power Supply.

## 2. INSTRUMENT DESCRIPTION

The electronic portion of a quadrupole mass spectrometer consists of the following sub-assemblies.

- (1) Electrometer amplifiers for measuring the very small signal currents, derived from an electron multiplier.
- (2) A programmer to select the masses to be measured and the order in which they are sampled.
- (3) The DC amplifier and RF oscillator which supply the signals to the quadrupole rods that are necessary for mass focussing.

- (4) The high voltage power supply for the electron multiplier biasing.
- (5) The housekeeping and monitor circuits.
- (6) The low voltage converter power supply.
- (7) Test Console.

## 2.1 Electrometer Amplifiers

The schematic for the two logarithmic amplifiers used to measure the spectra data and aperture current is shown on Drawing D-873.

The amplifiers have a logarithmic transfer characteristic and provide an output voltage of from zero to five volts for an input current range of  $5 \times 10^{-11}$  amps to  $5 \times 10^{-6}$  amps. The transfer function of a typical logarithmic amplifier is plotted on 5 cycle Lin-Log paper as shown in Figure 2.

The amplifiers are designed around very high input impedance ( $10^{15}$  ohms) integrated operational amplifiers. This design uses Intersil ICH 8500A amplifiers and are designated U<sub>1</sub> and U<sub>5</sub> on Drawing D-873.

The logarithmic characteristic is obtained from the relationship between the collector current and the emitter base voltage of standard junction transistors.

The base emitter voltage changes approximately 58 millivolts for every decade change of input current at 25°C. The 58 millivolts is amplified by use of a  $\beta$  network consisting of R<sub>2</sub>, R<sub>4</sub>, and S<sub>1</sub> so that the output presented to telemetry is 1 volt per decade.

The transistors  $Q_1$  and  $Q_2$  are dual NPN, PNP in the same T0-5 can. A dual transistor is used to compensate for the change in the base emitter voltage with temperature.

The compensation is accomplished by holding the collector current in the transistor on the right hand side ( $Q_1$ ,  $Q_2$ ) at a constant value. The change in VBE with temperature is approximately 2 millivolts per degree centigrade.

If the right hand side tracks the left hand side a  $\frac{\Delta V}{\Delta T}$  change will appear at the common emitter point and not at the output.

To prevent latch up from opposite polarity inputs (spikes, transients etc.) each amplifier has a reverse polarity limiter.

For the spectra electronics  $Q_3$  will conduct and prevent the amplifier from going into an "open loop" state in the event of a positive input current.

In the aperture electronics, diode  $CR_6$  serves the same purpose for negative input current.

Each electrometer has a buffer amplifier for voltage level shifting into the telemetry range of 0 to 5 volts, and also to provide isolation from long lines.

## 2.2 Programmer

The LASSII Mass Spectrometer Programmer is designed to have five modes, any one of which can be selected by

ground command. The contract work statement requested that the first four modes were to be sit modes while the fifth mode would scan up to 32 different masses. A design change was introduced into the programmer such that the four sit modes can also be used as mini-scan modes. A selection of from one to eight different masses can now be programmed in modes 1 through 1V.

The mode selection is accomplished through the ground control to spacecraft command link and stored in the experiment on latching relays  $K_1$  to  $K_4$  (Drawing D-1026.)

The relays in turn change the operation of the digital logic to produce the five different modes.

The digital logic and memory (Drawing D-1026) are used to control the voltage output of a 10 bit digital to analog converter  $U_9$ . A particular voltage output from  $U_9$  can be related to a particular mass, and it is this parameter that is controlled in the process of mass selection.

For laboratory adjustments a ten bit binary counter  $U_8$  is used to produce a linear sweep output from the digital to analog converter  $U_9$ .

When the programmer is in the mode selectable operation, the DAC is controlled by a pair of PROMS  $U_6$  and  $U_7$ .

The PROMS  $U_6$  and  $U_7$  are in turn controlled or addressed by either the counter  $U_5$  and  $U_6$  or by another PROM  $U_3$ .

PROMS  $U_6$  and  $U_7$  have data stored in them which relates to the selected masses. The PROM can store up to 32 mass positions and will probably be programmed to generate the MODE V "All Masses of Interest" scan.

The mode V scan will be generated by the binary counter  $U_4$  and  $U_5$  sequencing through the 32 address of memories  $U_6$  and  $U_7$ .

In modes I through IV the counter  $U_4$  and  $U_5$  is inhibited and the data presented at the jar inputs of  $U_4$  and  $U_5$ , appears at the outputs. Therefore, the address of memories  $U_6$  and  $U_7$  can be stored as data in memory  $U_3$ . Memory  $U_3$  is controlled by the command logic relays and a counter  $U_{15}$ . The counter allows for up to eight different masses in modes I through IV. If only one mass is desired then  $U_3$  will be programmed with the same data at eight different positions.

Also included in the programmer is a ten bit staircase which is generated by  $U_{14}$  and  $U_{11}$ . This output can be superimposed on the mass selection analog voltage, at the rate of ten increments per unit mass scan.

The mass scan is stepped along at a rate of 10 ms per mass step, and the staircase at 1 increment per ms.

### 2.3.1 DC Amplifiers

The DC amplifiers (Drawing D-1028) supply equal but opposite polarity voltages to the quadrupole rods. The voltage amplitude depends on the particular mass to be focussed and must be maintained at a fixed ratio relative to the peak RF amplitude in order to obtain good mass resolution. The amplifiers are linear and are capable of sweeping from 0 to  $\pm$  60 volts relative to a fixed rod bias of

-15 volts. The circuit is designed around an integrated high voltage operational amplifier such as the Burr Brown type 3582J and are shown schematically as  $U_2$   $U_3$  on Drawing D-1028.

The input to the DC amplifier is derived from the digital to analog converter which appears in program schematic Drawing D-1026. The output of the DC sweep is divided down by resistors  $R_{13}$  and  $R_{14}$  and supplied to telemetry in a 0 to 5 volt level by way of 1/4 of the quad operational amplifier  $U_1$ .

### 2.3.2 RF Oscillator

The RF oscillator (Drawing C-857) consists of two sections, the oscillator proper, and the control and monitor section.

The oscillator is a tuned secondary, Hartley oscillator with the frequency being determined by the inductance of the secondary winding and the rod capacitance. The secondary is split and capacitively coupled so that a  $\pm$  DC voltage can also be applied to the rods.

The amplitude and power to the oscillator is controlled by the base drive of transistors  $Q_1$  and  $Q_2$ . A servo loop consisting of amplifiers  $U_1$ ,  $U_2$  and  $U_3$  maintain the peak RF amplitude at a fixed ratio relative to the DC. The output of a control winding is peak detected by  $U_3$  and summed into the input of  $U_1$  which in turn supplies the base drive of transistors  $Q_1$  and  $Q_2$ . Ferrite beads are used in the oscillator base drive windings and in the control winding to suppress parasitic oscillations. The predominant parasitic is usually about twenty mega hertz for this particular layout.

The oscillator coil is wound on a one inch diameter hollow cylinder of polystyrene and has a turns ratio of 1,2,2,1 in the primary and a 104 turn center tap secondary. The frequency of oscillation is fixed at about 3.5 mega-hertz and the amplitude varied from 0 to 600 volts peak to peak. The oscillator coil is mounted in a shielded cavity and isolated from the rest of the circuits to minimize RF interference. Conductive interference is minimized by use of LC filters in the  $\pm$  DC sweep lines, the +28 line and also on the  $\pm$  15 volt lines.

#### 2.4 High Voltage Power Supply

The high voltage power supply is manufactured by Velonex, Inc. of Santa Clara, California.

The power supply is contained in a welded metal can with the dimensions of 1.25" by 1.75 by 1.75. The output is a nominal 3000 volts with a  $\pm$  500 volt adjustment.

The power supply is used to Bias a 20 stage Johnson Laboratory Electron Multiplier Model MM-1. The power supply and electron multiplier are mounted on a plate directly behind the quadrupole rods.

#### 2.5 Monitor Circuits

The monitor circuits provide an insight to the performance of the instrument as a function of time and temperature.

An on board commutator is used to sample various power supply voltages, two temperature indicators and a mode indicator.

The commutator circuit is drawn on Schematic D-1028, and consists of a counter  $U_6$  and a CMOS analog multiplexer  $U_5$ . The counter  $U_6$  will be driven by a 1 pulse per second signal supplied by the spacecraft.

The power supply monitors are resistor dividers with operational amplifiers used where level shifting is required.

The temperature monitors were designed around a Fenwal Thermistor Type GA51J11, and are located in each package. The thermistors are purchased with a threaded screw type mount and are attached directly to the aluminum chassis.

A curve of output voltage versus temperature appears in Figure 1.

The mode monitor is a voltage staircase generated by relays  $K_1$  to  $K_4$  and is shown on Schematic D-1026.

## 2.6 Low Voltage Converter

A low voltage converter is necessary because of the range of the various biases required in the operation of a mass spectrometer.

The input regulator for the power supply (Drawing D-1023) was originally designed as a switching regulator using a Fairchild ua78S40.

Problems in the manufacturing of the ua78S40 resulted in delayed deliveries of the component, and a fixed voltage regulator of the ua78GKM type was installed to prevent delays in the testing of the instruments.

The input to the converter is protected from a reverse polarity being applied by the diodes CR<sub>3</sub> and CR<sub>4</sub>. The filter C<sub>1</sub>, L<sub>1</sub> and C<sub>2</sub> is used to reduce any conducted interference from the experiment and may be changed during EMI testing.

The transformer is wound on a toroid and potted in a heat conductive epoxie.

The frequency of oscillation for the transformer, with a 20 volt input is about five kilo-hertz.

Post regulators U<sub>2</sub>, U<sub>3</sub> and U<sub>4</sub> are used to minimize drift in the low voltage analog circuits.

## 2.7 Test Console

A test console is supplied with the mass spectrometer experiment to allow for field tests without the need of a large number of test instruments.

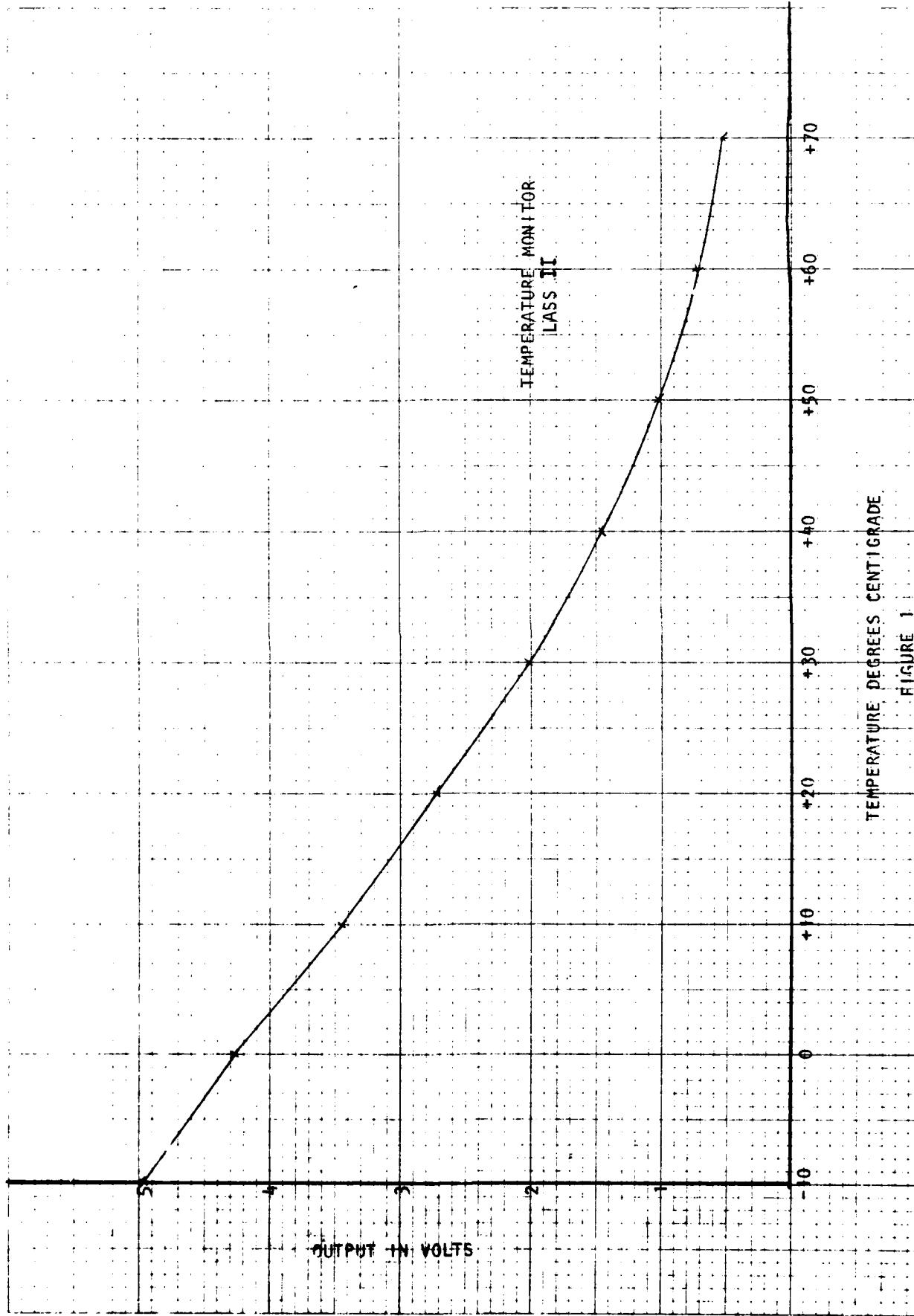
The test console will supply the power and timing functions and display mode and data signals received from the experiment.

A photograph of the front panel appears in Figure 5.

Auxilliary jacks are available to allow for more precise measurements of each parameter.

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C. V. P. & C. H. P. INC.

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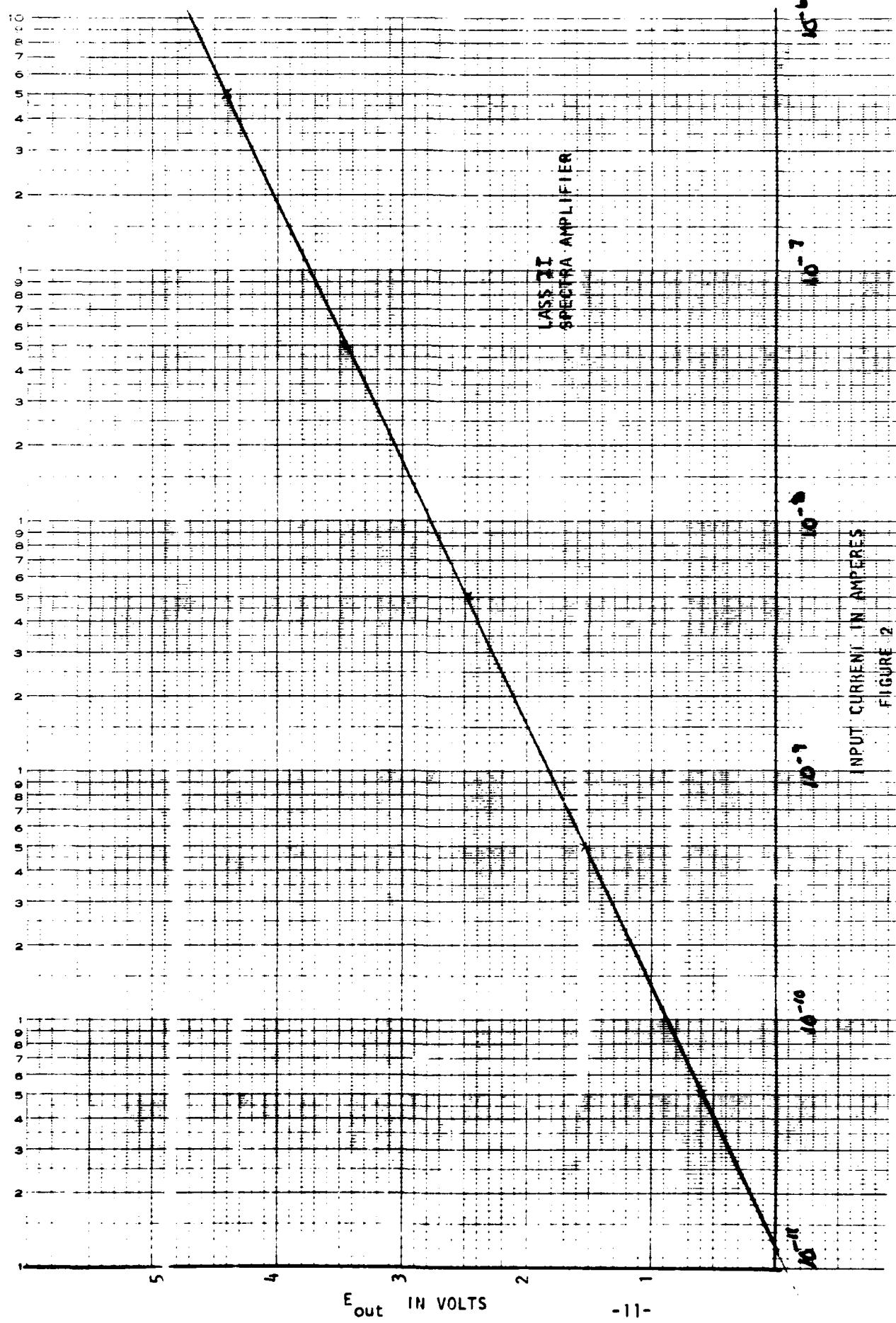


TEMPERATURE, DEGREES CENTIGRADE

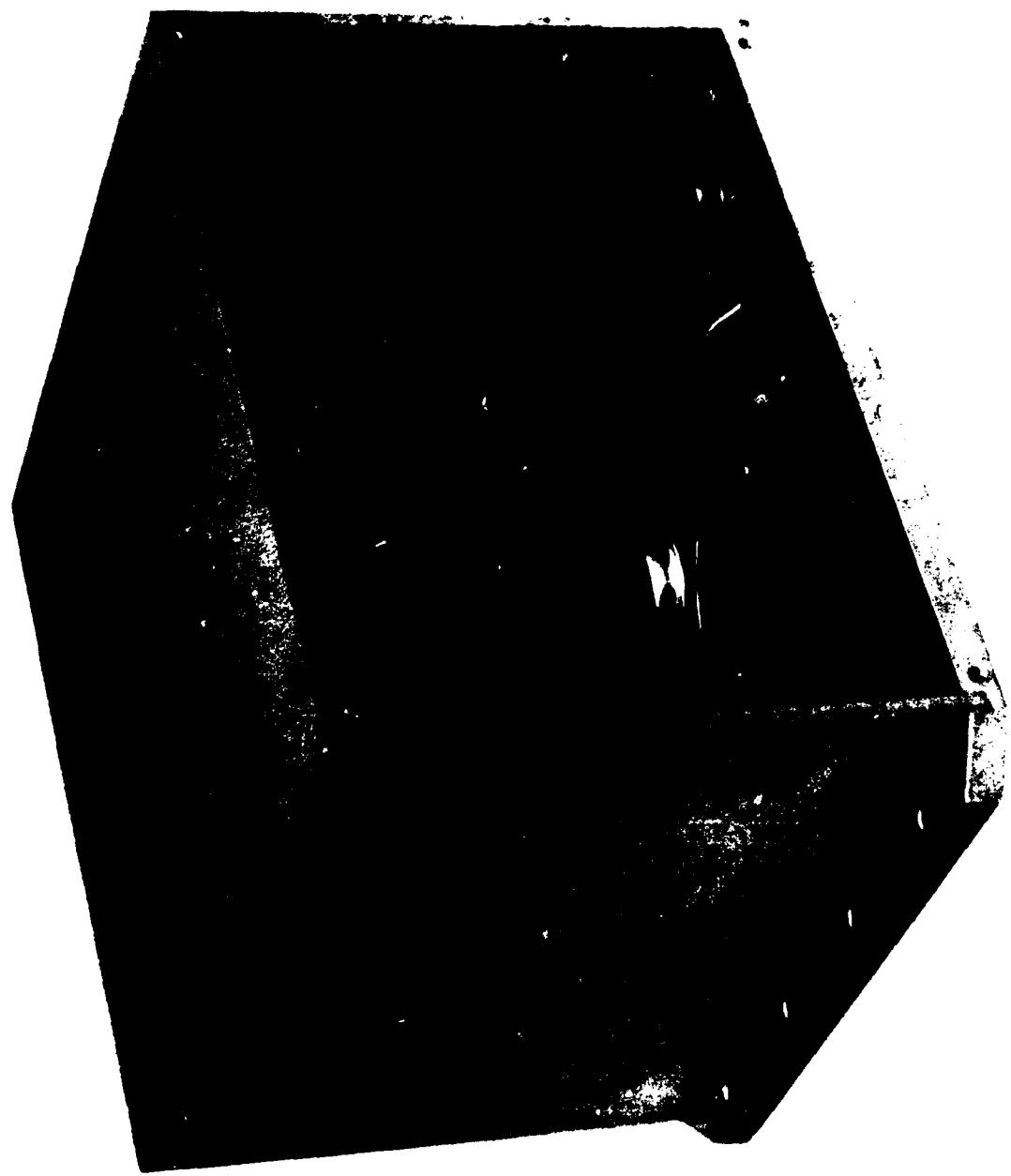
FIGURE 1

No. 34-1001. DIETZGEN GRAPH PAPER  
STANDARD LOGARITHMIC  
5 CYCLES X 10 DIVISIONS PER INCH

DIETZGEN CORPORATION  
MANUFACTURERS OF  
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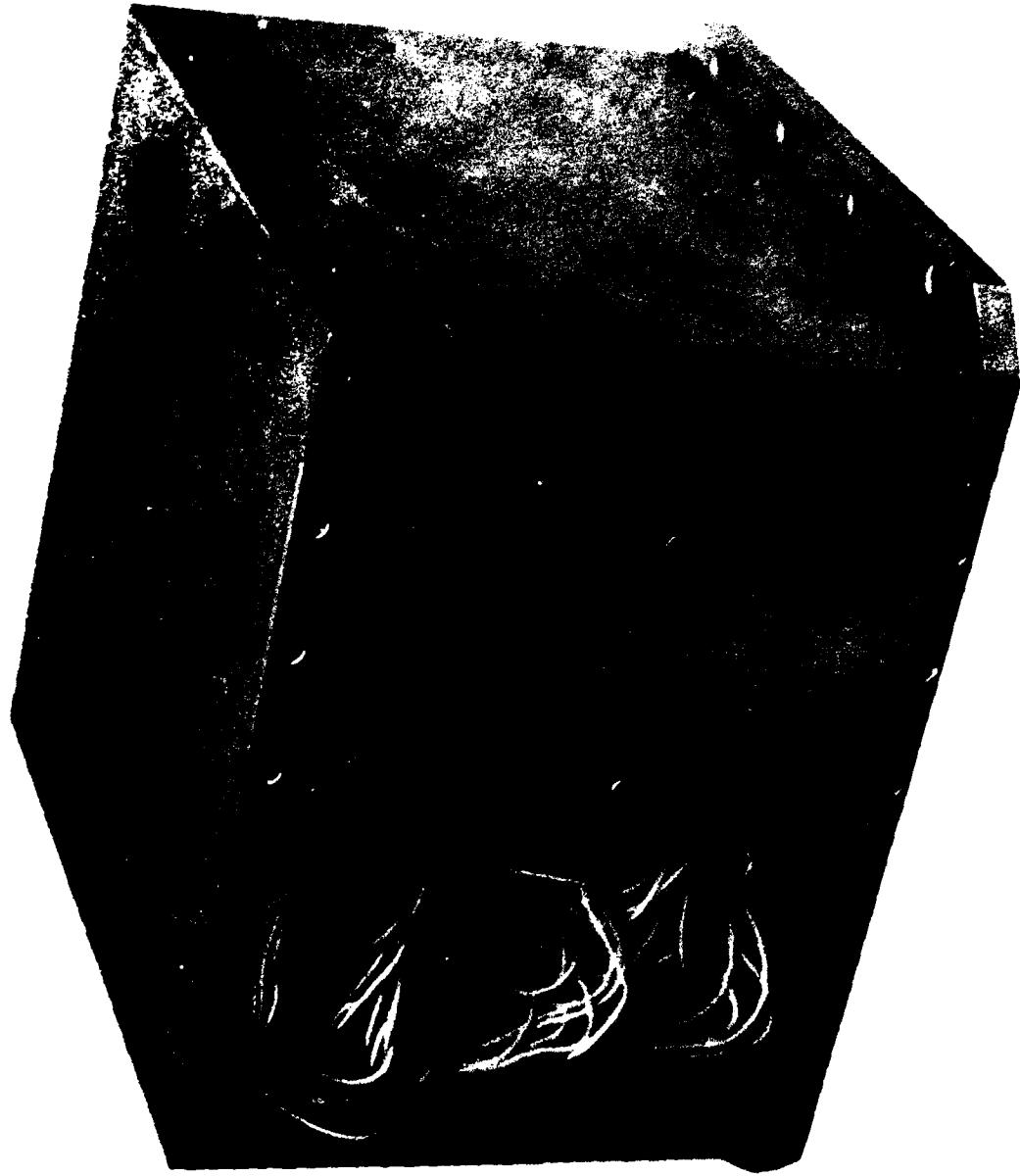


**INPUT CURRENT IN AMPERES**

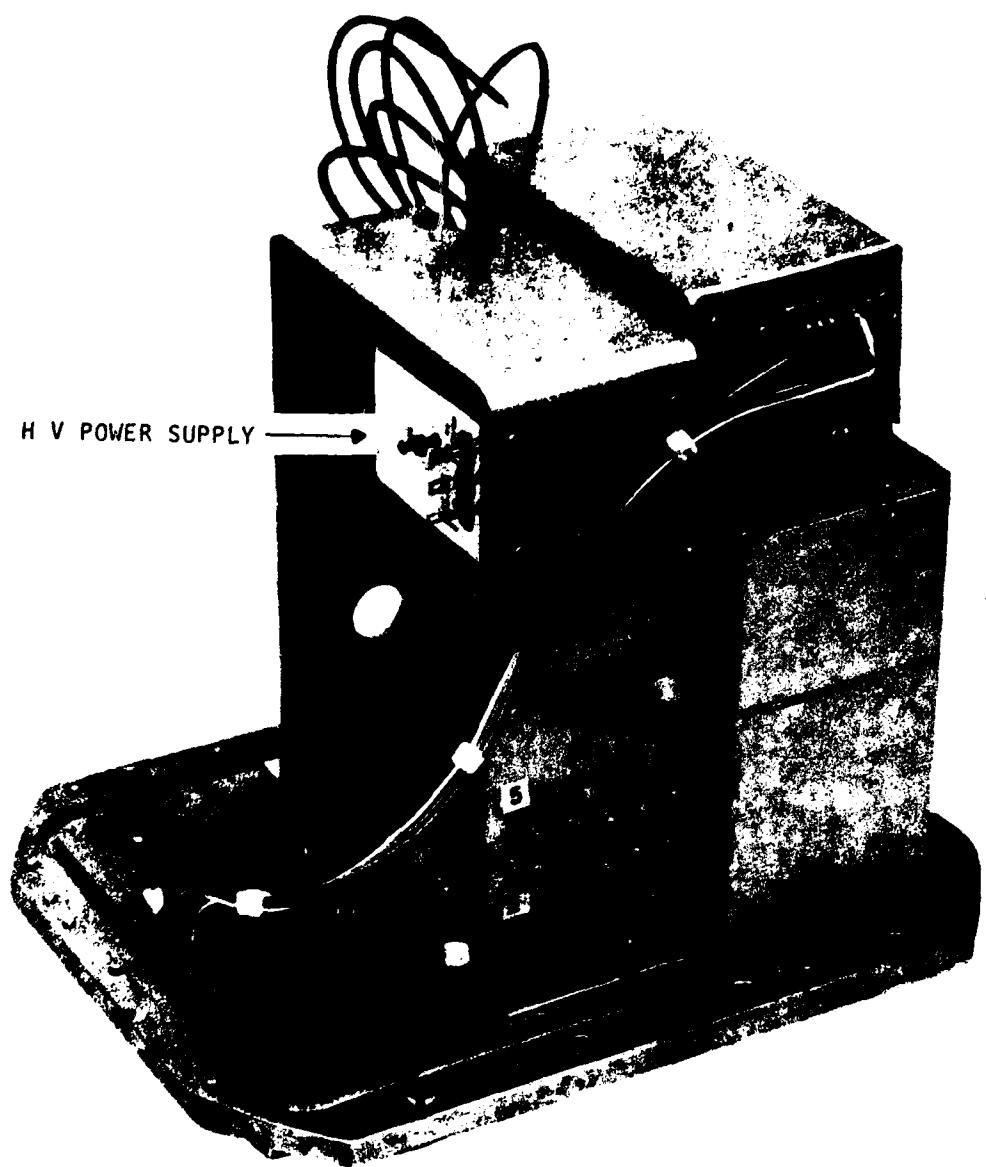


ELECTRONIC BOX FRONT FIGURE 3

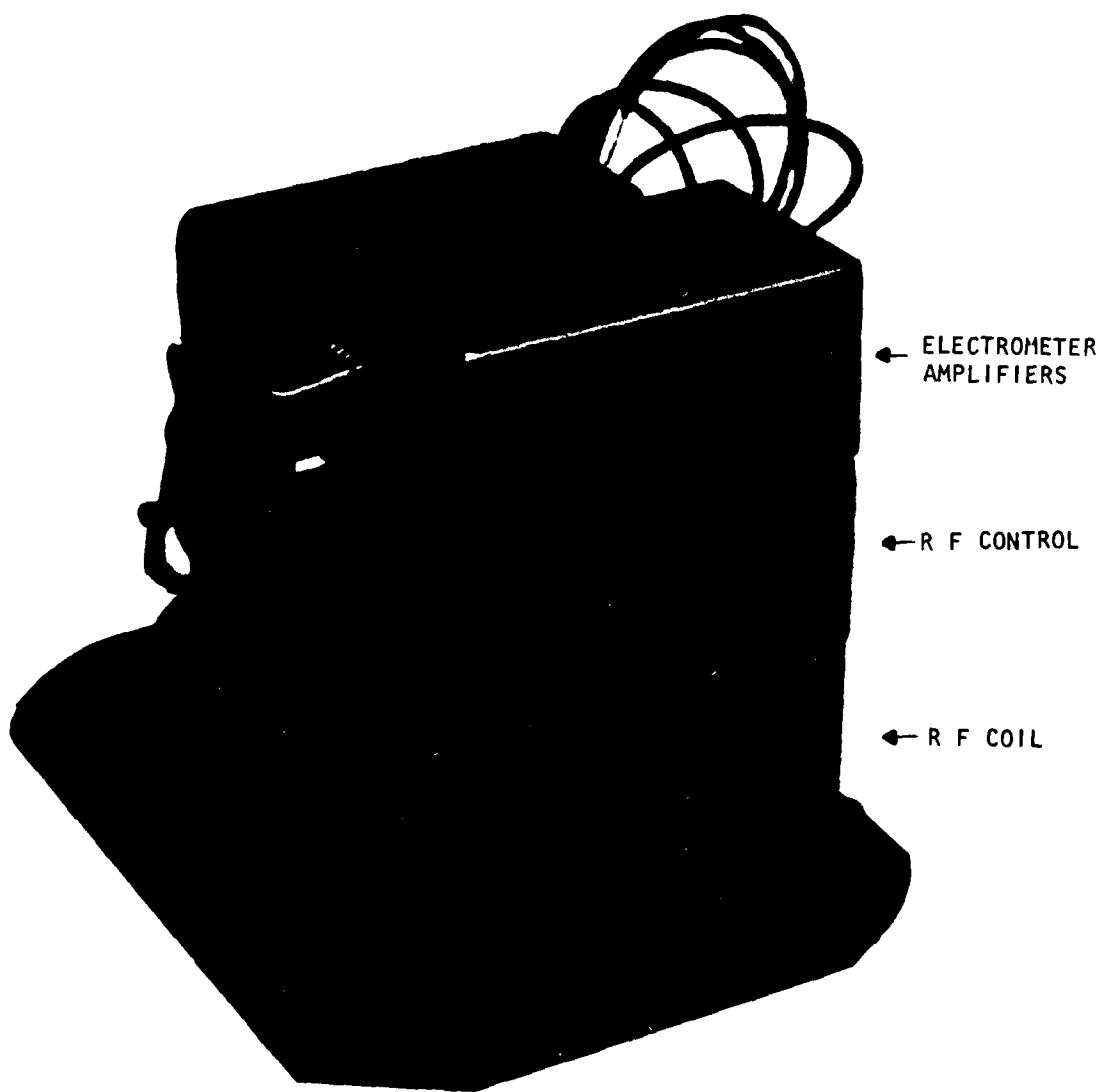
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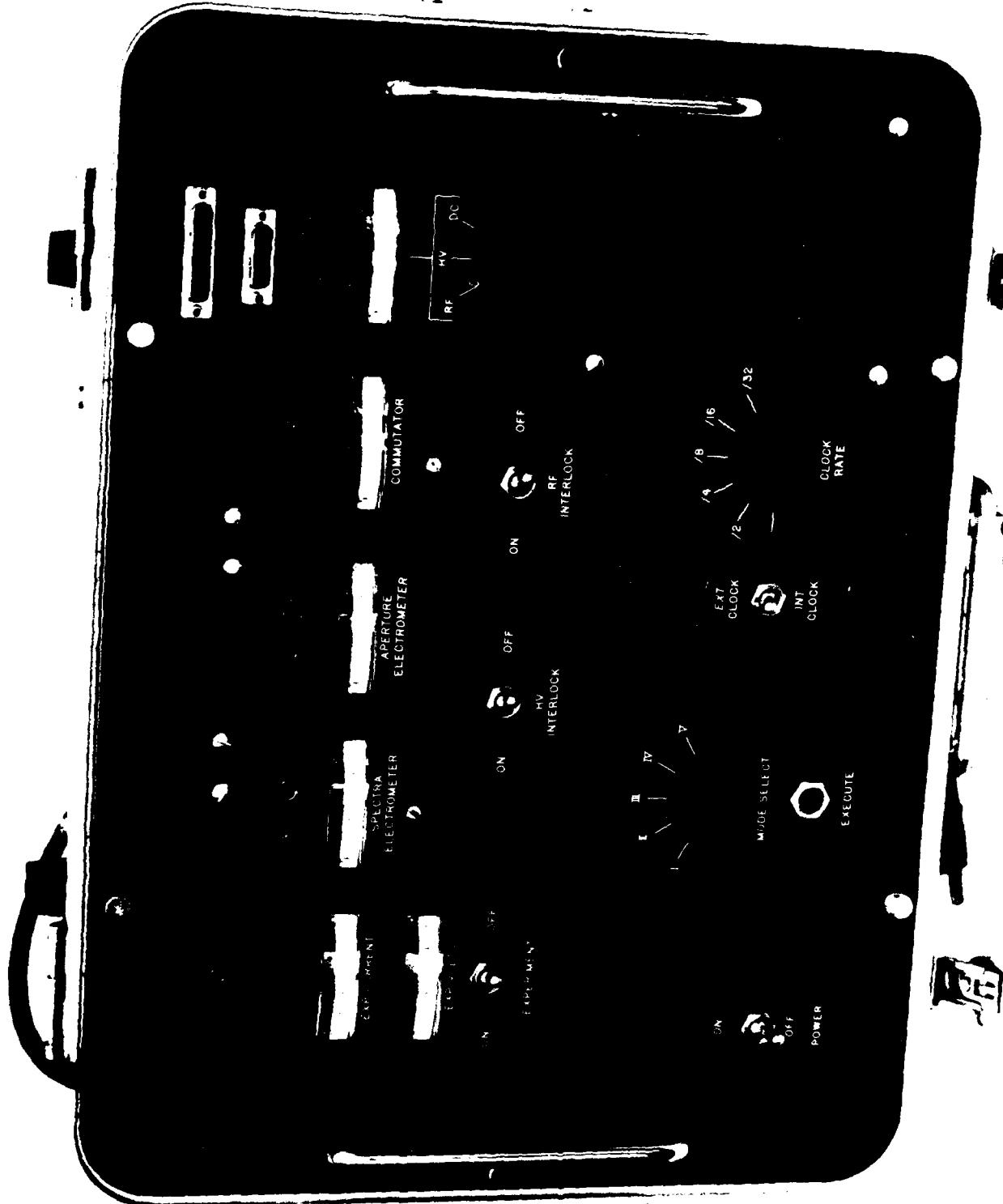
ELECTRONIC BOX REAR FIGURE 3



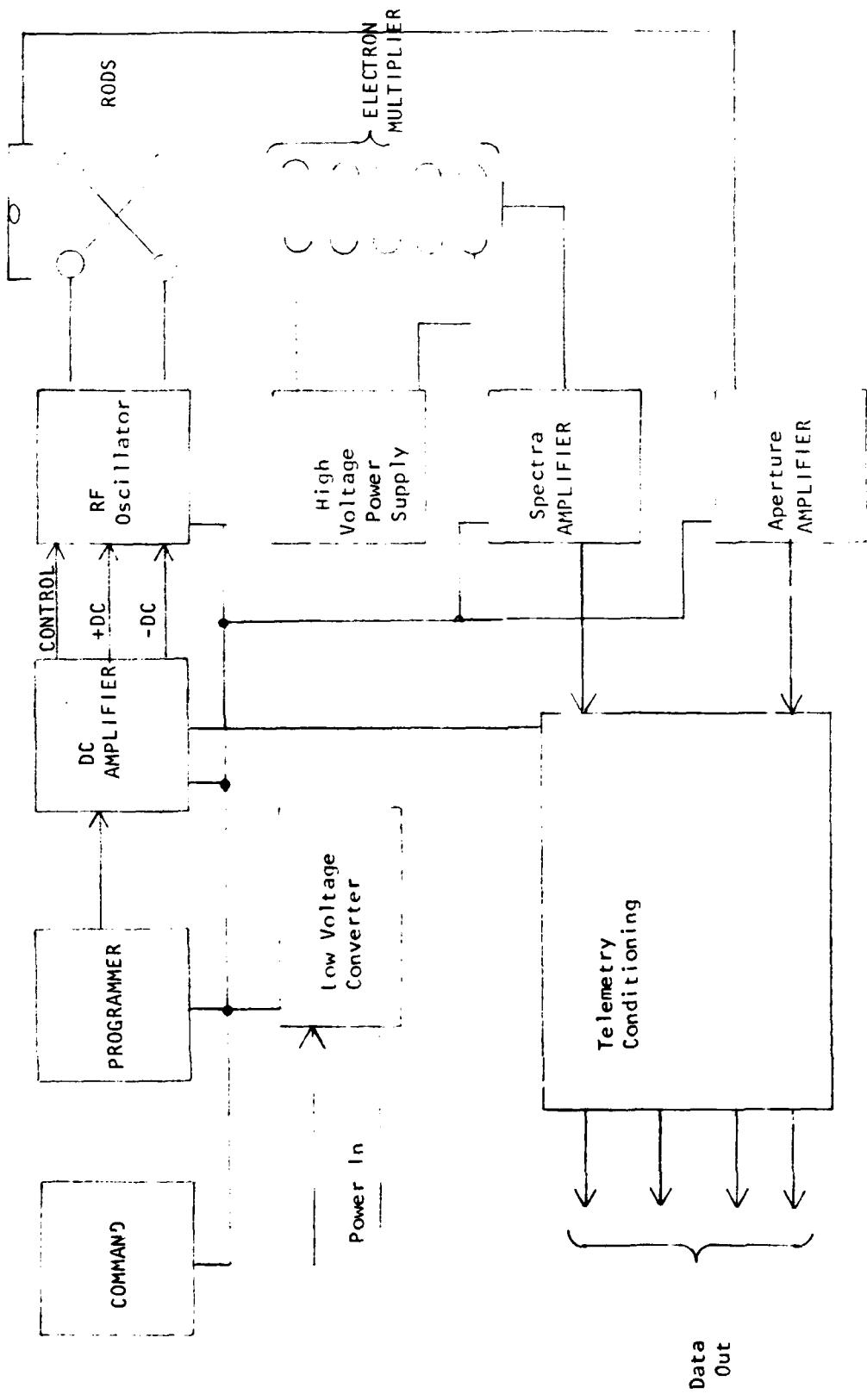
SENSOR PACKAGE FIGURE 4



SENSOR PACKAGE FIGURE 4

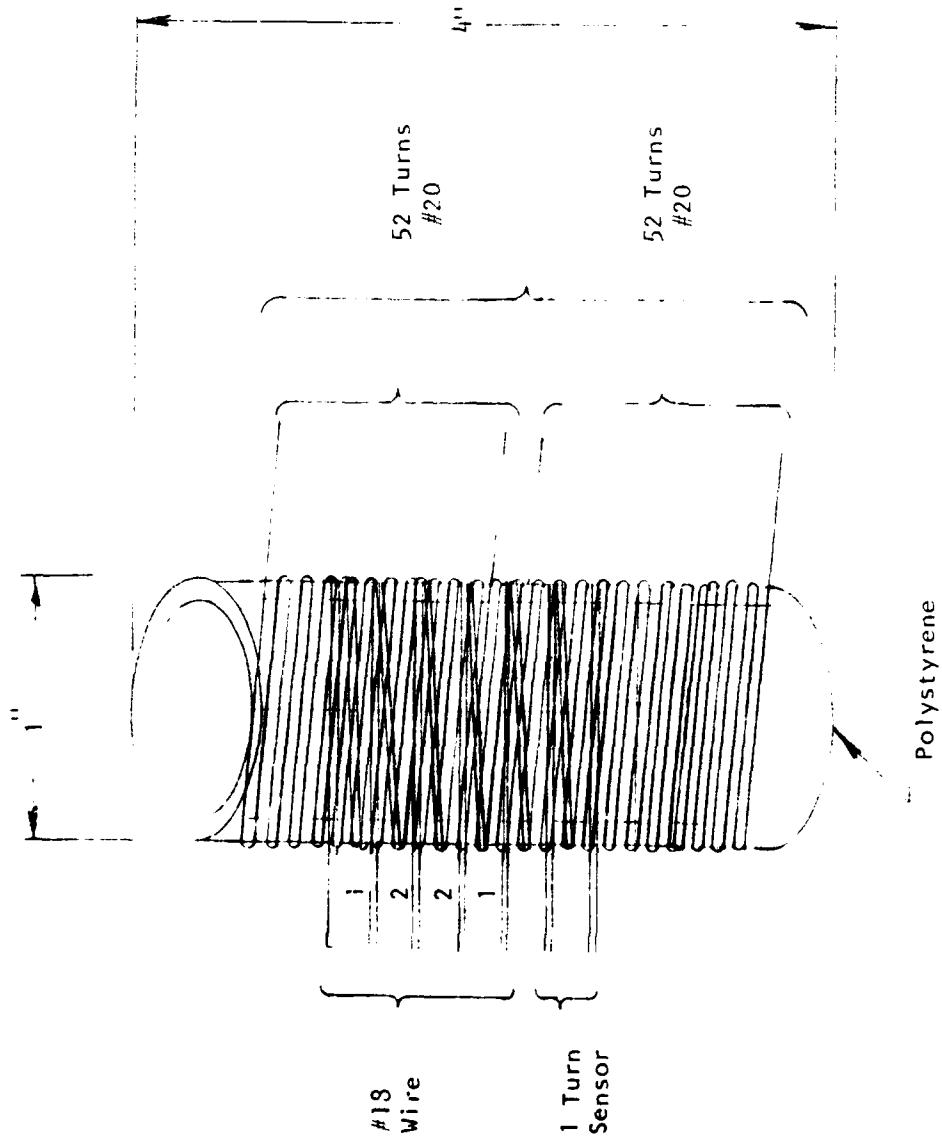


TEST CONSOLE FIGURE 5



BLOCK DIAGRAM

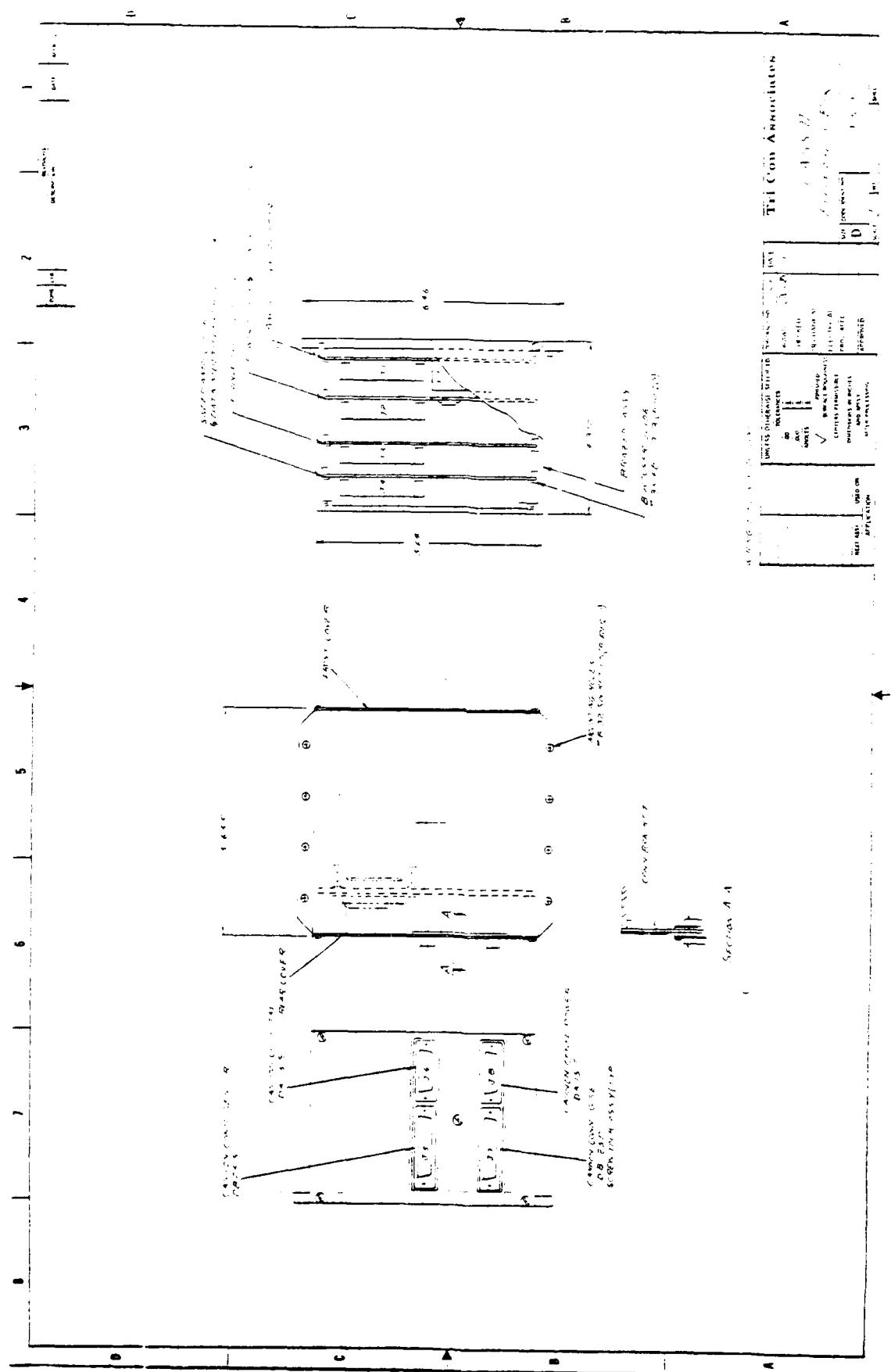
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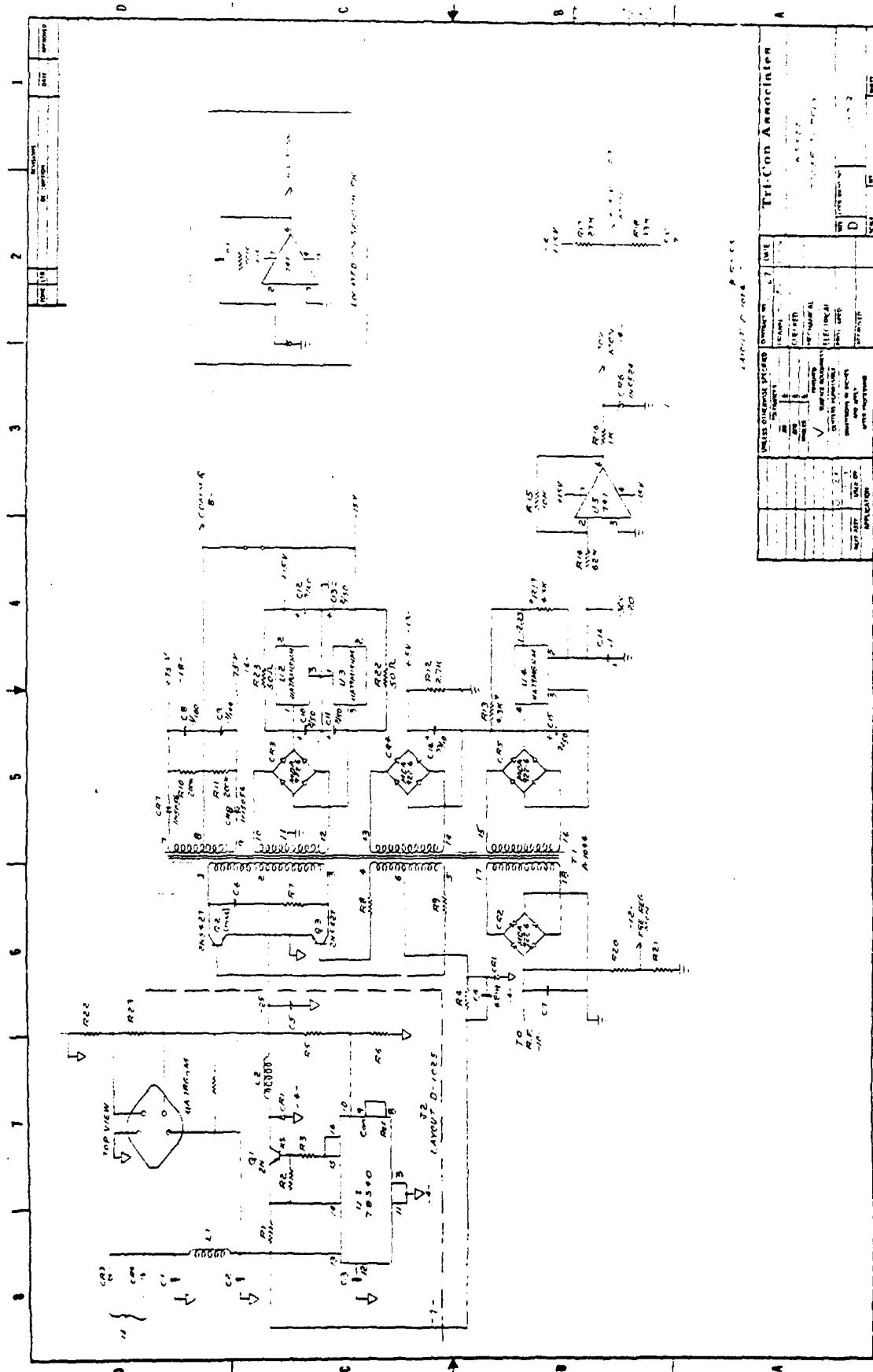


RF OSCILLATOR

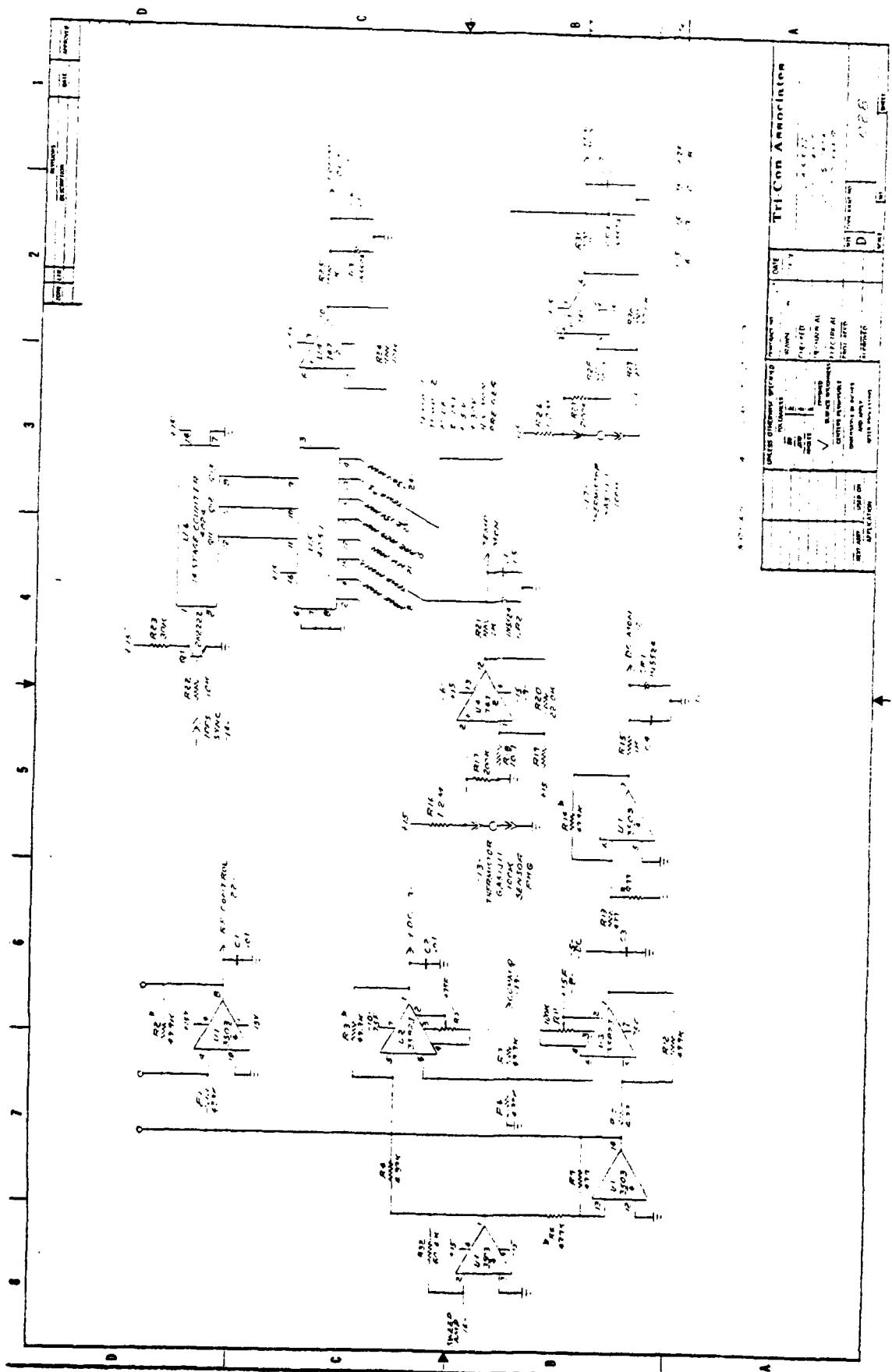
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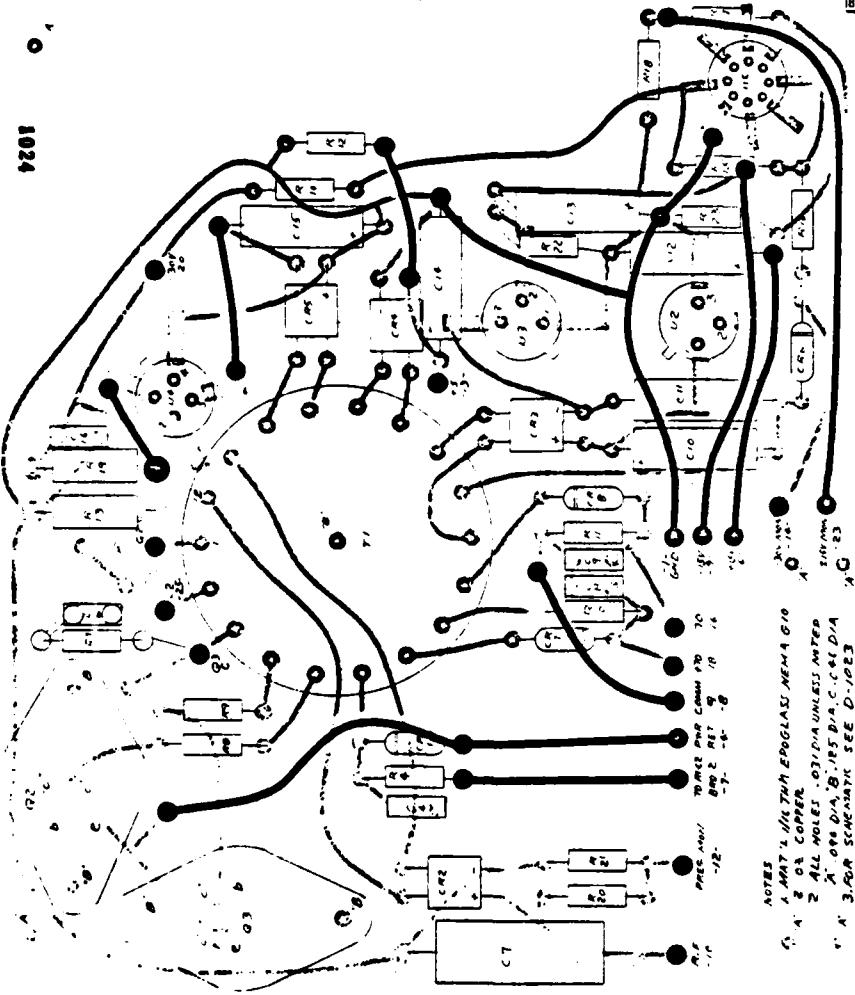






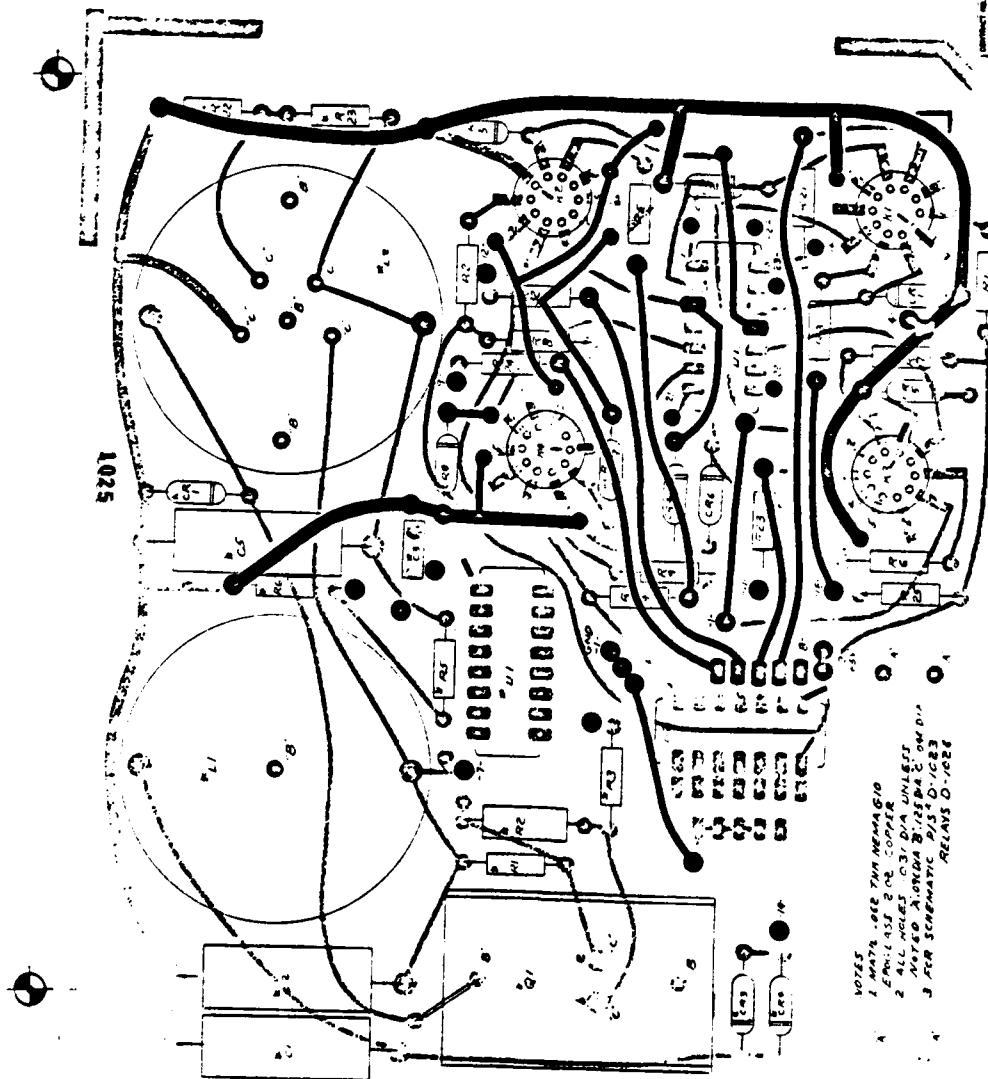






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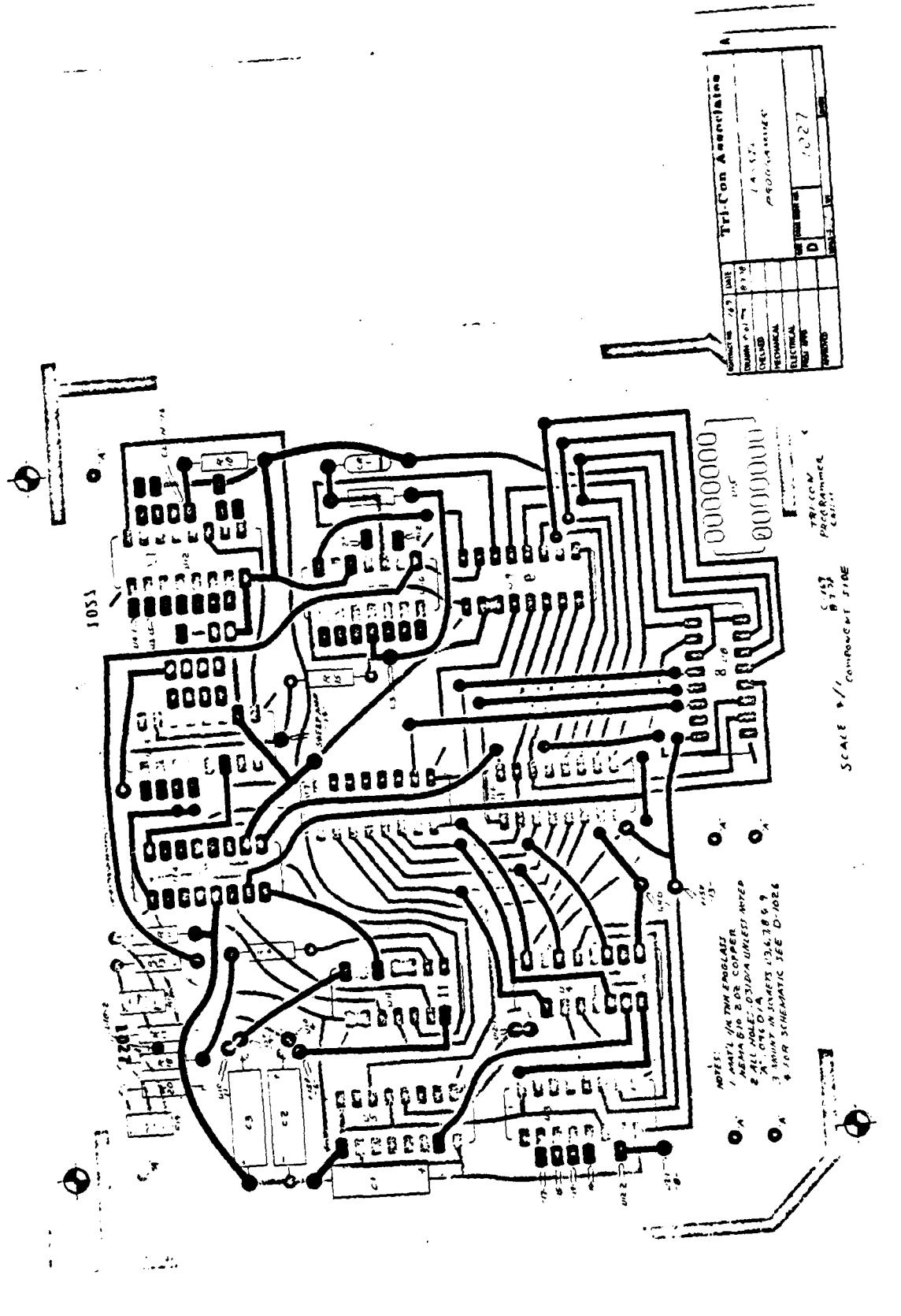


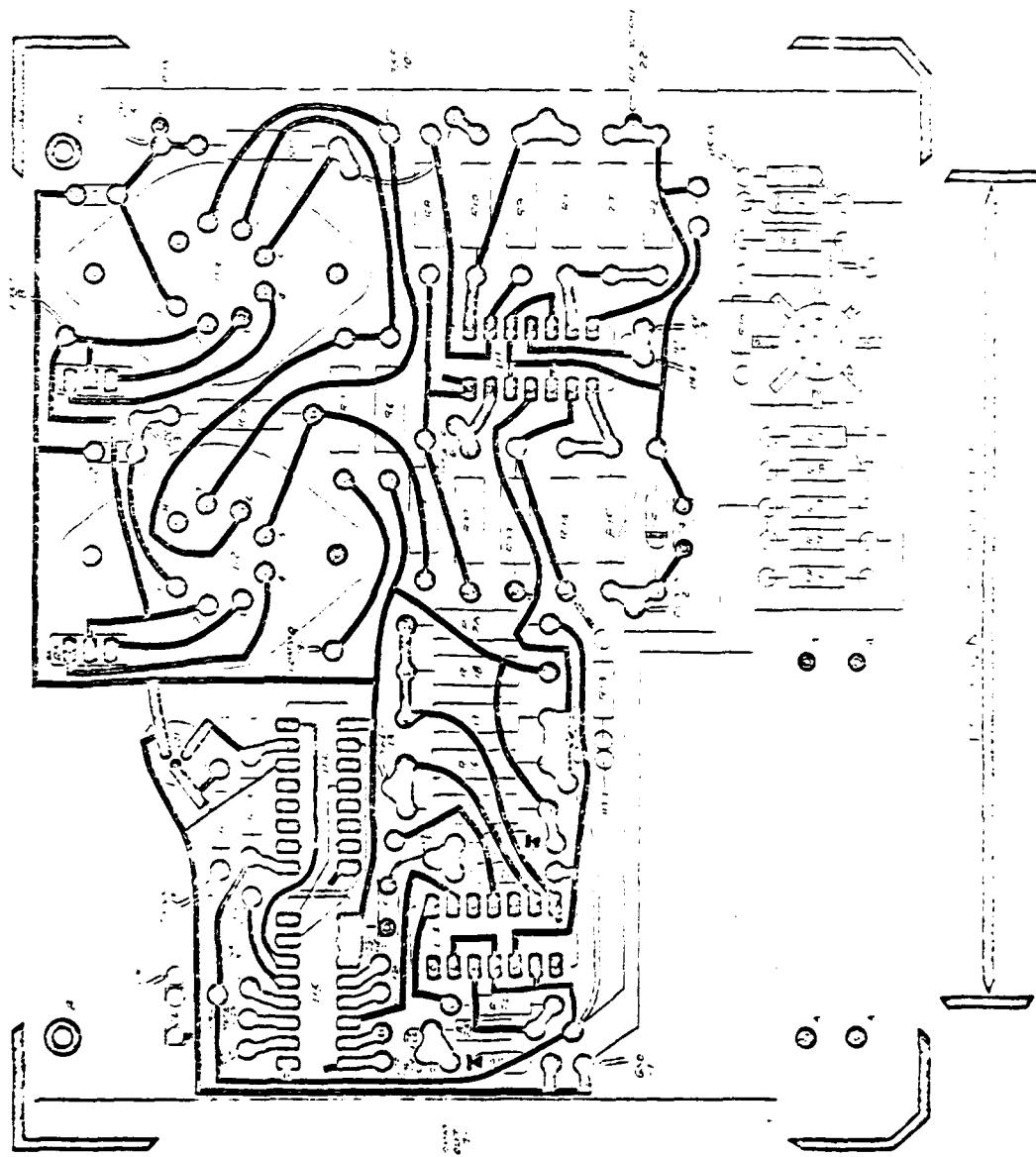
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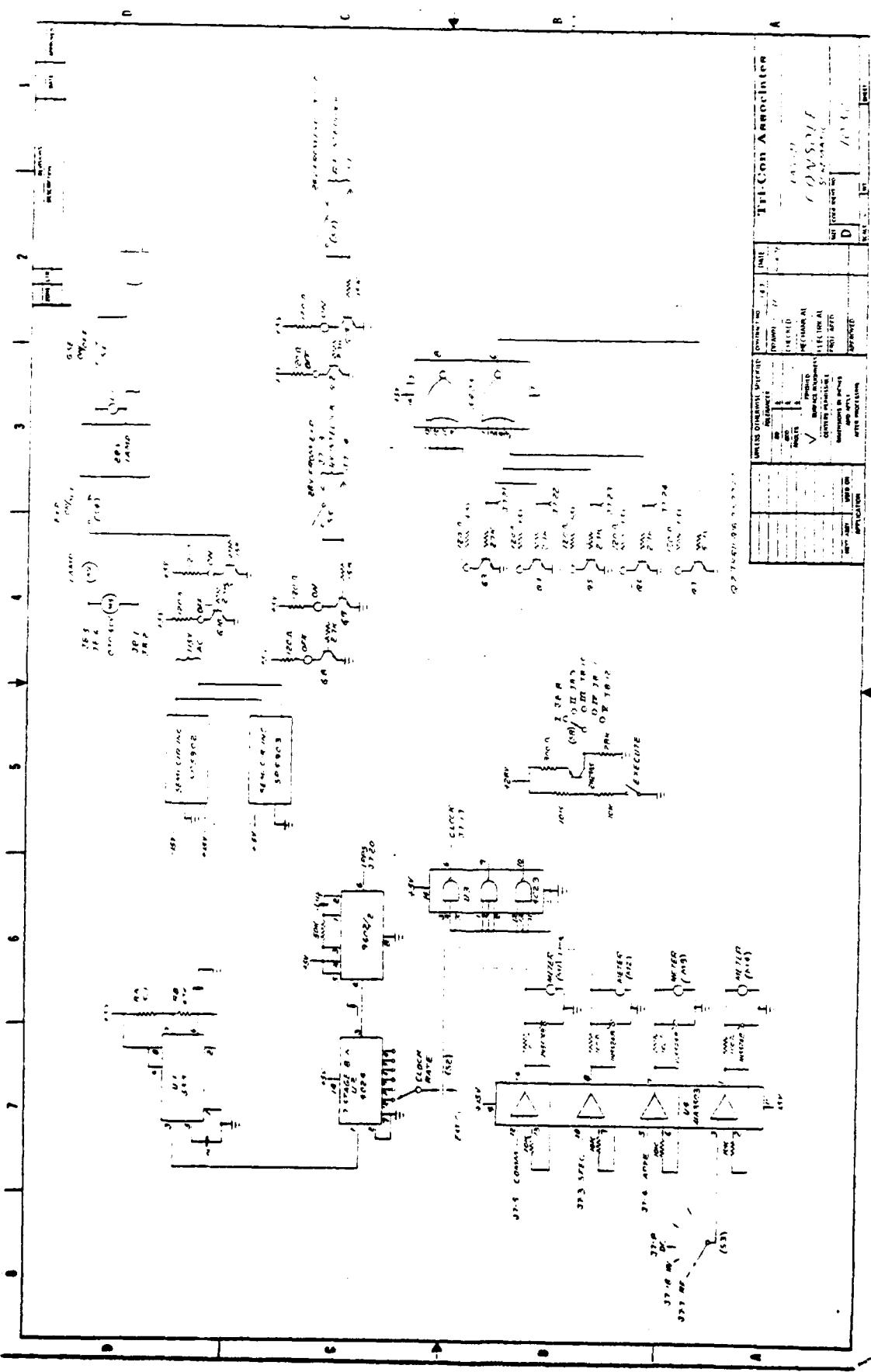
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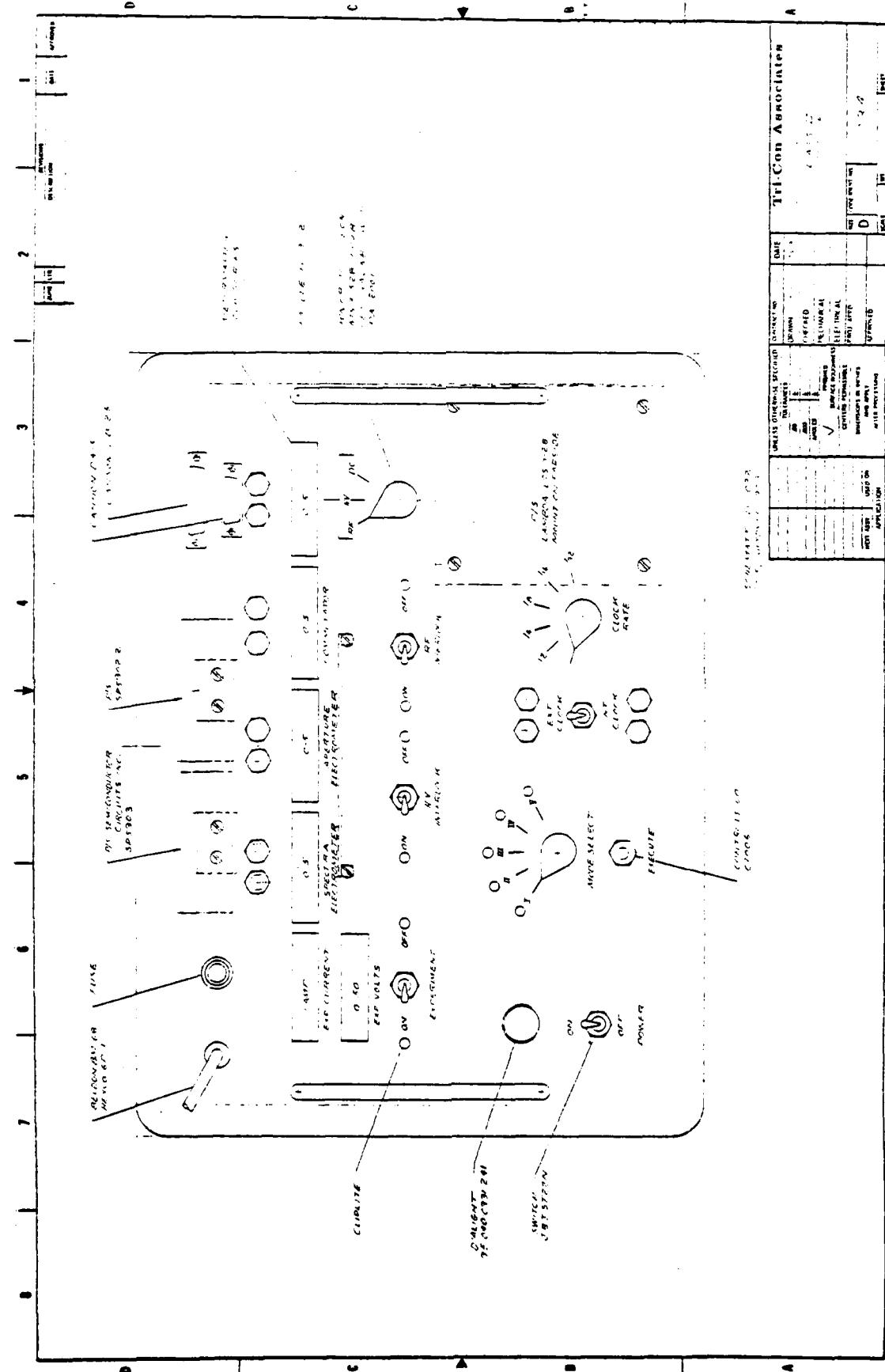
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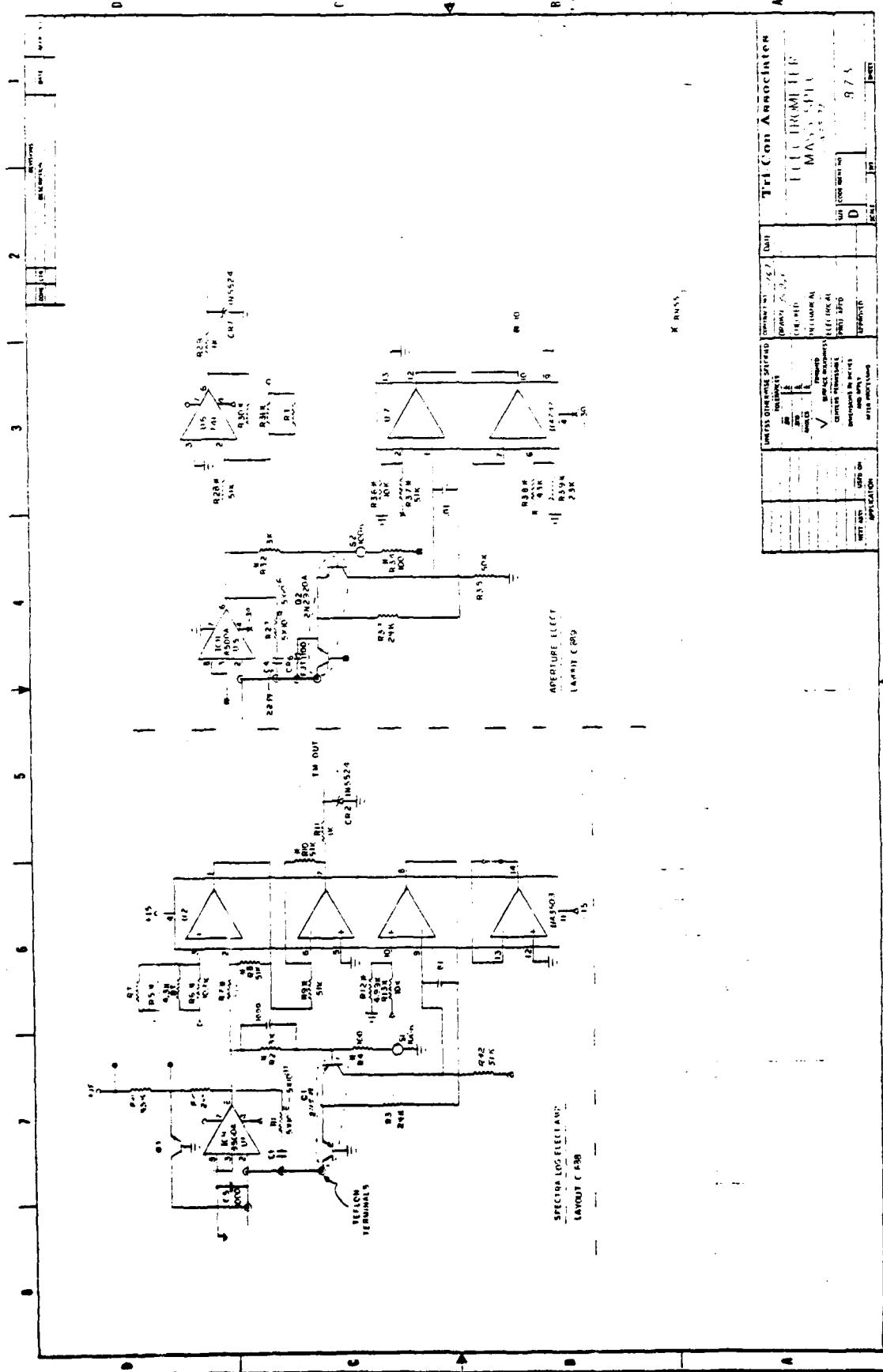
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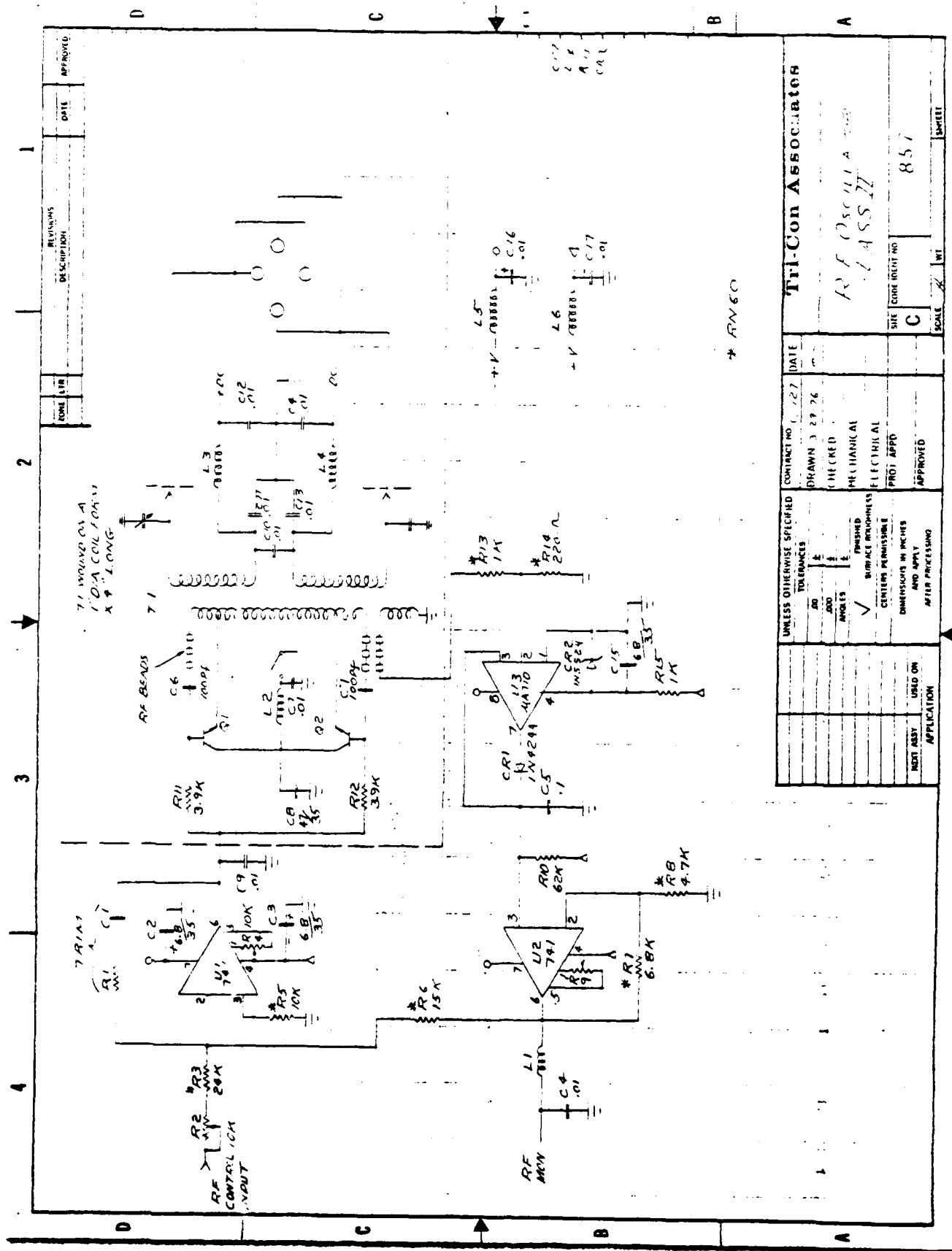


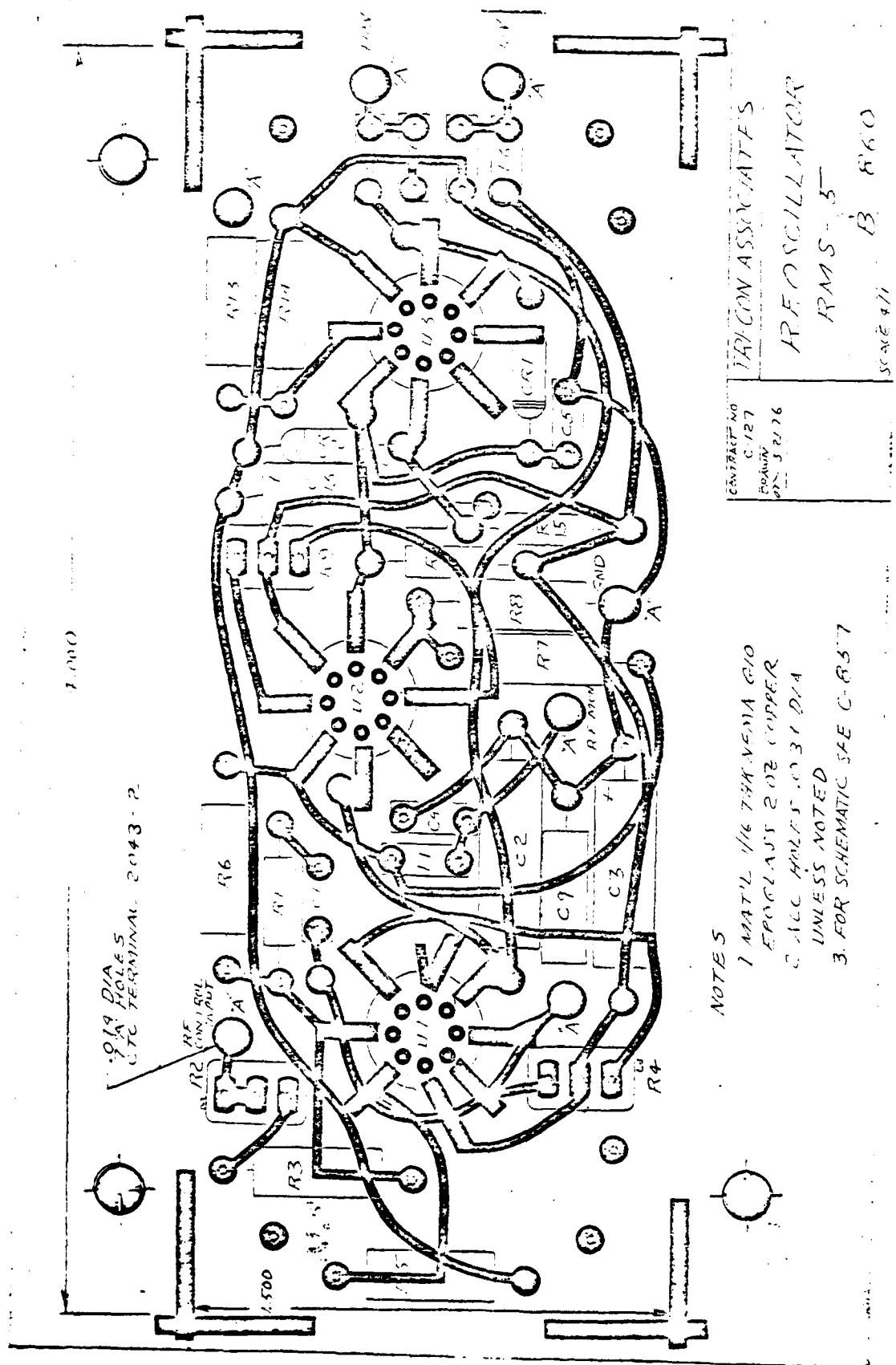


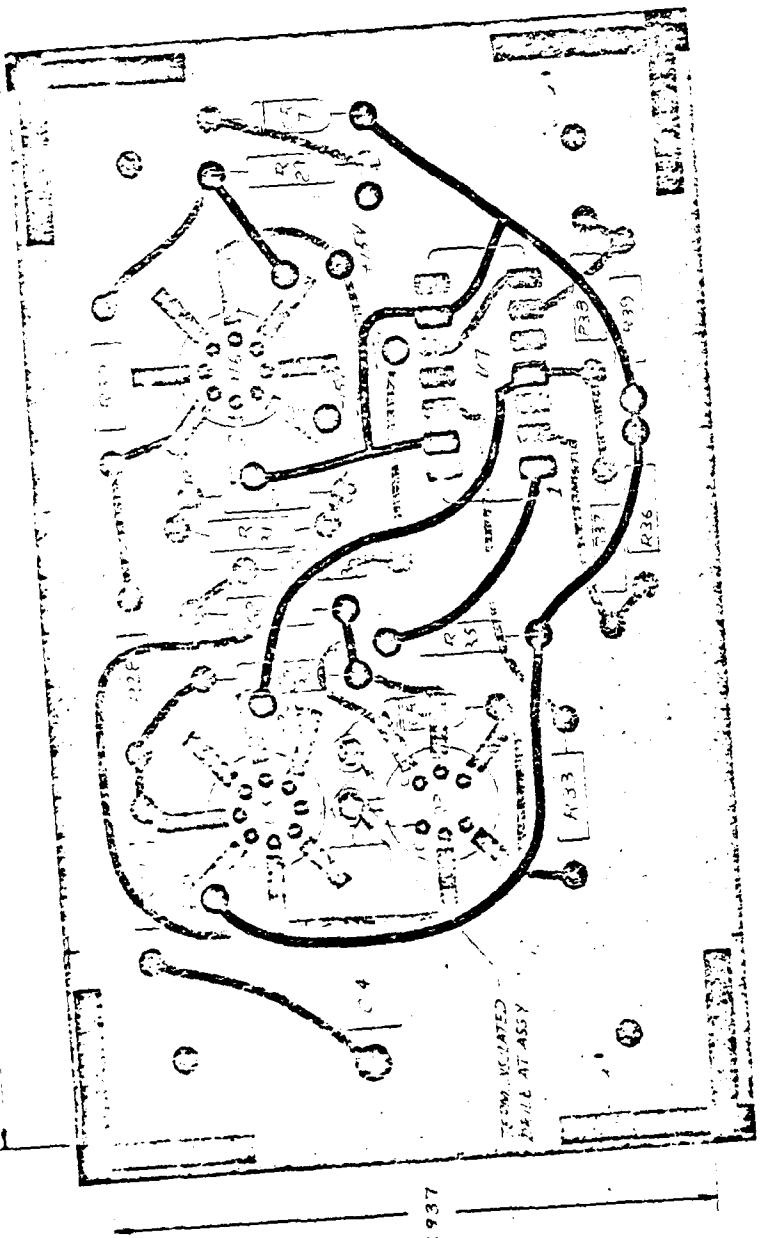




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**NOTES**

1. NAT'L 1/8 IN. NEAGG. IN. FROGGLASS
2. OR COOPER 2 SIDED
3. ALL HOLES .031 DIA
4. LINELESS NOTED
5. XDP SCHEMATIC SEE D-873

|                                    |  |                    |  |
|------------------------------------|--|--------------------|--|
| TRI-CON ASSOCIATES                 |  | DATE<br>10-18-77   |  |
| 1111 N. 17TH ST. PHOENIX, AZ 85007 |  | TELE 2-2417        |  |
| C-169                              |  | SHEET 1/2          |  |
| UNLESS OTHERWISE SPECIFIED         |  | CONTRACT NO. C-169 |  |
| TOLERANCES                         |  | DRAWN BY           |  |
| DO                                 |  | CHECKED BY         |  |
| 0.00                               |  | MECHANICAL         |  |
| ANODIZED                           |  | ELECTRICAL         |  |
| FINISHED SURFACE ROUGHNESS         |  | PROT. APPRO.       |  |
| CENTERS PERMISSIBLE                |  | APPROVED           |  |
| DIMENSIONS IN INCHES               |  | AND APPLY          |  |
| AFTER PROCESSING                   |  |                    |  |
| PRINT ASSY                         |  | PRINT ON           |  |
| SPECIFICATION                      |  | SHEET              |  |